16.01.2003

PCT/GR03/00003

ΟΡΓΑΝΙΣΜΟΣ ΒΙΟΜΗΧΑΝΙΚΗΣ ΙΔΙΟΚΤΗΣΙΑΣ (ΟΒΙ)

ΠΙΣΤΟΠΟΙΗΤΙΚΟ

REC'D 17 FEB 2003
WIPO PCT

Βεβαιώνουμε ότι τα έγγραφα που συνοδεύουν το πιστοποιητικό αυτό, είναι ακριβή και πιστά αντίγραφα της κανονικής αίτησης για Δίπλωμα Ευρεσιτεχνίας, με αριθμό **20020100037**, που κατατέθηκε στον Οργανισμό Βιομηχανικής Ιδιοκτησίας στις **12/02/2002**, από το Ινστιτούτο Μικροηλεκτρονικής,**ΕΚΕΦΕ«ΔΗΜΟΚΡΙΤΟΣ»**,που εδρεύει στο Τέρμα Πατριάρχου Γρηγορίου, 15310, Αγία Παρασκευή και την κα **Ανδρούλα Νασιοπούλου, ΕΚΕΦΕ «ΔΗΜΟΚΡΙΤΟΣ»**, που εδρεύει στο Τέρμα Πατριάρχου Γρηγορίου, 15310, Αγία Παρασκευή.

PRIORITY DOCUMENT
SUBMITTED OR TRANSMITTED IN COMPLIANCE WITH RULE 17.1(a) OR (b)

Μαρούσι, 24/01/2003

Για τον Ο.Β.Ι.
Ο Γενικός Διευθυντής

Εμμανουήλ Σαμουηλίδης

PRIORITY DOCUMENT
SUBMITTED OR TRANSMITTED IN COMPLIANCE WITH RULE 17.1(a) OR (b)

ΟΡΓΑΝΙΣΜΟΣ ΒΙΟΜΗΧΑΝΙΚΗΣ ΙΔΙΟΚΤΗΣΙΑΣ ΟΒΙ

ΠΑΝΤΑΝΑΣΣΗΣ 5. 151 25 ΠΑΡΑΔΕΙΣΟΣ ΑΜΑΡΟΥΣΙΟΥ - ΤΗΛ.: 61 83 506 - FAX: 68 19 231

ΟΡΓΑΝΙΣΜΟΣ
ΒΙΟΜΗΧΑΝΙΚΗΣ
ΙΔΙΟΚΤΗΣΙΑΣ

ΑΙΤΗΣΗ ΓΙΑ ΧΟΡΗΓΗΣΗ

ΔΙΠΛΩΜΑΤΟΣ ΕΥΡΕΣΙΤΕΧΝΙΑΣ (ΔΕ)
Ή
ΔΙΠΛΩΜΑΤΟΣ ΤΡΟΠΟΠΟΙΗΣΗΣ (ΔΤ)
Ή
ΠΙΣΤΟΠΟΙΗΤΙΚΟΥ ΥΠΟΔΕΙΓΜΑΤΟΣ ΧΡΗΣΙΜΟΤΗΤΑΣ (ΠΥΧ)

συμπληρώνεται από τον ΟΒΙ

Αριθμός αίτησης:	20020100037	01
Ημερομηνία παραλαβής:	24 ΙΑΝ. 2002	
Ημερομηνία κατάθεσης:	24 ΙΑΝ. 2002	

Με την αίτηση αυτή ζητείται:

X	ΔΙΠΛΩΜΑ ΕΥΡΕΣΙΤΕΧΝΙΑΣ (Δ.Ε.)	02
	ΔΙΠΛΩΜΑ ΤΡΟΠΟΠΟΙΗΣΗΣ (Δ.Τ.) ΣΤΟ Δ.Ε. με αριθμό:	
	ΠΙΣΤΟΠΟΙΗΤΙΚΟ ΥΠΟΔΕΙΓΜΑΤΟΣ ΧΡΗΣΙΜΟΤΗΤΑΣ (Π.Υ.Χ.)	

Η αίτηση αυτή είναι τμηματική της αίτησης με αριθμό: 03

ΤΙΤΛΟΣ ΤΗΣ ΕΦΕΥΡΕΣΗΣ: 04

Low power silicon thermal flow sensor and microfluidic devices using porous silicon sealed air cavity or microchannels

ΚΑΤΑΘΕΤΗΣ 05

όνομα ή επωνυμία: ΕΚΕΦΕ «ΔΗΜΟΚΡΙΤΟΣ», Ινστιτούτο Μικροηλεκτρονικής

διεύθυνση ή έδρα: Τέρμα Πατριάρχου Γρηγορίου, 153 10 Αγία Παρασκευή Αττικής

εθνικότητα:

τηλέφωνο: 6542783, 6533781 τέλεξ: τέλεφαξ: 6533781

2 ΕΠΙΠΛΕΟΝ ΚΑΤΑΘΕΤΕΣ ΣΕ ΠΡΟΣΘΕΤΟ ΦΥΛΛΟ ΧΑΡΤΙΟΥ 06

αριθμός

ΟΡΓΑΝΙΣΜΟΣ
ΒΙΟΜΗΧΑΝΙΚΗΣ
ΙΔΙΟΚΤΗΣΙΑΣ

K

ΕΝΤΥΠΟ ΓΙΑ ΕΠΙΠΛΕΟΝ ΚΑΤΑΘΕΤΕΣ

ΑΙΤΗΣΗΣ
ΔΙΠΛΩΜΑΤΟΣ ΕΥΡΕΣΙΤΕΧΝΙΑΣ (ΔΕ)
'Η
ΔΙΠΛΩΜΑΤΟΣ ΤΡΟΠΟΠΟΙΗΣΗΣ (ΔΤ)
'Η
ΠΙΣΤΟΠΟΙΗΤΙΚΟΥ ΥΠΟΔΕΙΓΜΑΤΟΣ ΧΡΗΣΙΜΟΤΗΤΑΣ (ΠΥΧ)

Αριθμός αίτησης	20020100037	19
Ημερομηνία παραλαβής.	2 4 [illegible] 2002	
Ημερομηνία κατάθεσης.	2 4 [illegible] 2002	

ΚΑΤΑΘΕΤΗΣ 20

όνομα ή επωνυμία: Ανδρούλα Νασιοπούλου

διεύθυνση ή έδρα: ΕΚΕΦΕ "ΔΗΜΟΚΡΙΤΟΣ", Ινστιτούτο Μικροηλεκτρονικής, Τέρμα Πατριάρχου Γρηγορίου, 153 10 Αγ.Παρασκευή Αττικής

εθνικότητα: Ελληνική

τηλέφωνο: 65542783, 6533781 τέλεξ: τέλεφαξ: 6511723

ΚΑΤΑΘΕΤΗΣ 21

όνομα ή επωνυμία:

διεύθυνση ή έδρα:

εθνικότητα:

τηλεφωνο: τέλεξ: τέλεφαξ:

	ΕΠΙΠΛΕΟΝ ΚΑΤΑΘΕΤΕΣ ΣΕ ΠΡΟΣΘΕΤΟ ΦΥΛΛΟ ΧΑΡΤΙΟΥ.	22

αριθμός

ΕΦΕΥΡΕΤΗΣ		07
	Ο(ι) καταθέτης(ες) είναι ο(οι) μοναδικός(οί) εφευρέτης(ες).	
X	Έντυπο ορισμού του(των) εφευρέτη(ών) επισυνάπτεται.	

ΑΞΙΩΣΕΙΣ 08

Αριθμός αξιώσεων: ☐

ΔΗΛΩΣΗ ΠΡΟΤΕΡΑΙΟΤΗΤΑΣ (αριθμός - ημερομηνία - χώρα προέλευσης) 09

ΠΛΗΡΕΞΟΥΣΙΟΣ 10

όνομα:

διεύθυνση:

τηλέφωνο: τέλεξ: τέλεφαξ:

ΑΝΤΙΚΛΗΤΟΣ 11

όνομα: ΑΝΔΡΟΥΛΑ ΝΑΣΙΟΠΟΥΛΟΥ

διεύθυνση: ΕΚΕΦΕ "ΔΗΜΟΚΡΙΤΟΣ", Ινστιτούτο Μικροηλεκτρονικής, Τέρμα Πατριάρχου Γρηγορίου, 153 10 Αγ.Παρασκευή Αττικής

τηλέφωνο: 6542783, 6533781 τέλεξ: τέλεφαξ: 6511723

ΔΙΕΘΝΗΣ ΕΚΘΕΣΗ		12
	Η εφεύρεση παρουσιάστηκε σε επίσημα αναγνωρισμένη έκθεση, σύμφωνα με το ν. 5562/1932, ΦΕΚ 221Α/32.	
	Σχετική βεβαίωση επισυνάπτεται. .	

ΥΠΟΓΡΑΦΗ(ΕΣ) ΤΟΥ(ΤΩΝ) ΚΑΤΑΘΕΤΗ(ΩΝ) ή ΤΟΥ(ΤΩΝ) ΠΛΗΡΕΞΟΥΣΙΟΥ(ΩΝ). 13

Τόπος: Αγ. Παρασκευή Αττικής Ημερομηνία 21/1/2002

Δρ Α. Νασιοπούλου

Καθ. Δ. Ιθακήσιος

Δ/ντής & Πρόεδρος Δ.Σ. ΕΚΕΦΕ"Δ"

ΠΑΡΑΚΑΛΟΥΜΕ Η ΑΙΤΗΣΗ ΝΑ ΕΙΝΑΙ ΔΑΚΤΥΛΟΓΡΑΦΗΜΕΝΗ ΚΑΘΩΣ ΚΑΙ ΤΟ ΟΝΟΜΑ ΚΑΤΩ ΑΠΟ ΤΗΝ ΥΠΟΓΡΑΦΗ. ΣΕ ΠΕΡΙΠΤΩΣΗ ΝΟΜΙΚΟΥ ΠΡΟΣΩΠΟΥ ΝΑ ΔΑΚΤΥΛΟΓΡΑΦΗΘΕΙ ΚΑΙ Η ΙΔΙΟΤΗΤΑ ΤΟΥ ΥΠΟΓΡΑΦΟΝΤΟΣ ΓΙΑ ΤΗΝ ΕΤΑΙΡΙΑ.

<u>Title:</u> "Low Power Silicon Thermal Sensors and Microfluidic Devices Using Porous Silicon Sealed Air Cavity or Microchannels"

Field of the invention

This invention relates to low power silicon thermal sensors and microfluidic devices, which use a micromachining technique to fabricate electrochemically porous silicon membranes with a cavity underneath. In the case of thermal sensors the structure used is of the closed type (porous silicon membrane on top of an air gap), while in microfluidics the same technique is used to open microchannels with a porous silicon membrane on top.

Description of the related art

Silicon thermal flow sensors are based on heat exchange between the fluid and the hot parts of the device, which are kept at relatively high temperature, of the order of 100 – 180 °C. In silicon thermal gas sensors, this temperature has, sometimes, to exceed 400 °C. In order to keep the temperature constant, the electric power on the heater has to compensate thermal losses due to conduction, convection and radiation. Losses due to conduction through the substrate on which the active elements of the device are fabricated can be minimized if this substrate is a thin membrane, instead of bulk crystalline silicon, which is a good thermal conductor (thermal conductivity K=145 W/m.K). Different methodologies were developed so far for the fabrication of membranes in the form of bridges suspended over a cavity in bulk silicon. By using bulk silicon micromachining techniques, Nassiopoulou and G. Kaltsas [Patent N°. OBI 1003010, Patent N° PCT/GR/00040, published by WIPO 12/11/1998] and G. Kaltsas and A. G. Nassiopoulou [Mat. Res. Soc. Symp. Proc. Vol. 459 (1997) 249, Microelectronic Engineering 35 (1997) 397] fabricated suspended polycrystalline or monocrystalline silicon membranes, using only front side optical lithography and porous silicon locally formed on bulk crystalline silicon as a sacrificial layer. Dusko et al. [Sensors and Actuators A, Vol.60, (1997) 235] , using a similar technique, fabricated suspended silicon nitride membranes. Both of the above techniques were used to fabricate silicon thermal sensors. A gas flow sensor was fabricated by G. Kaltsas and A. G. Nassiopoulou, Sensors and Actuators A, 76 (1999), p. 133-138 and a gas

sensor by C. Ducso, M. Adam, E. Vazsonyi, I. Szabo and I. Barsony, Eurosensors XI, Warsaw, Poland, Sept. 21-24, 1997). However, there is an important drawback in the above techniques. It is related to the fragility of the structures which makes any processing after membrane formation very difficult. An alternative method proposed and used by A. G. Nassiopoulou and G. Kaltsas (Greek patent No 1003010) and G. Kaltsas and A. G. Nassiopoulou, "Front-side bulk silicon micromachining using porous silicon technology", Sensors and Actuators: A, 65, (1998) p.175-179] uses slightly oxidized porous silicon as a material for local thermal isolation on bulk silicon. This approach offers important advantages related to the mechanical stability of the structure and the compatibility with further silicon processing. It has been successfully used to fabricate silicon thermal gas flow sensors by G. Kaltsas and A. G. Nassiopoulou [Sensors and Actuators 76 (1999) 133, Phys. Stat. Sol. (a) 182 (2000) 307]. In the present patent we propose a methodology to improve the above technique by combining the advantages of using a cavity (better thermal isolation) with the advantages of a rigid structure. The proposed structure is composed of a cavity sealed with porous silicon and fabricated in one process step by electrochemistry.

Summary of the invention

It is an object of this invention to provide a method for the fabrication of silicon thermal sensors with improved thermal isolation, based on the use of a sealed cavity on which the active elements of the sensor are developed. The sealed cavity is fabricated on bulk silicon by a two-step electrochemical process in which in the first step porous silicon is formed locally on bulk silicon by electrochemical dissolution with an anodization current below the limit for electropolishing and in a second step the current is increased so as the process is turned to electropolishing for the fabrication of a cavity underneath the porous layer. The silicon thermal sensor devices based on the above structure combine the good isolation properties offered by suspended membranes with the advantage of having a rigid structure. In the Greek patent N° OBI 1003010, a rigid and mechanically stable structure was also proposed, based on porous silicon locally formed on bulk silicon in order to provide local thermal isolation. The present approach is an improvement of that structure, because it offers both mechanical stability by the planar structure and better thermal isolation by the cavity underneath the porous layer. The critical value of current density for electropolishing (Jps) depends on the electrochemical solution used and on the resistivity and type of the silicon substrate. The thickness of the porous layer and the depth of the air gap are adjusted by adjusting the current density and the anodization time for the specific solution used. The smoothness of the bottom surface and sidewalls of the gap depend also on the electrochemical solution used. A schematic presentation of the above described structure is shown in fig.1 where (1) is the silicon substrate, and (2) is the porous silicon layer on top of the cavity (3).

It is also an object of the present invention to provide a thermal flow sensor device based on the above method. This sensor is illustrated in fig. 2. It is composed of a silicon substrate (1) on which a closed structure of a porous silicon membrane (2) with an air gap underneath (3) is formed locally by an electrochemical dissolution of silicon in an HF:ethanol solution. Depending on the thickness of the porous layer and the depth of the air gap, the mask for porous silicon formation is either a resist layer, or silicon nitride or a bilayer of SiO_2 and polycrystalline silicon. The active elements of the sensor are composed of a heater (4) and two thermopiles (5,6) on each side of the heater. The number of thermocouples in each thermopile depends on the needed sensitivity of the device. The hot contacts of the thermocouples (7) are on porous silicon and the cold contacts (8) on the bulk crystalline silicon substrate (1). The thermocouple material is n-type poly/Al or n-type/p-type poly. The first case limits the temperature of

operation of the device at around 400 °C, while the second permits operation at temperatures up to ~ 900 °C. The heater is composed of p-type polycrystalline silicon and it is maintained at constant power by using an external electronic circuit, which stabilizes the power by providing a current feedback if the temperature changes. The device can also operate at constant current on the heater, but the use of constant power is better in the case of a high flow range. Indeed, under flow the resistor is instantly cooled down by the gas flow and this causes a slight change of its resistance, which gives a measurable effect to the thermopiles output at high flow. This effect is minimized if the resistance change is compensated by a slight change in the current, so as to keep the power consumption constant.

It is also the object of the present patent to propose the use of the heated resistor both as heater and as temperature sensing element. Alternatively, two resistors may be integrated on both sides of the heater for temperature sensing. In the above two cases the power supply and readout electronics are different than in the case of the two thermopiles on each side of the heater.

The thermal isolation by porous silicon with an air gap underneath, compared to the use of a single porous silicon layer in contact with the substrate offers the advantage of reducing power consumption and increasing the sensitivity of the device. Simulations carried out using MEMCAD V.4.8 package by MICROPROSM showed that the improvement depends on porous layer thickness and air cavity depth. Fig. 3 shows the effect of porous layer thickness on the temperature of the heater for an air gap of 20 μm and a heat flux of 8.57×10^6 W/m^2 applied on a 530 μm long polysilicon heater of width 20 μm and thickness 0.5 μm. This corresponds to a supplied power of 71 mW. For comparison, the results of a compact structure, where there is no cavity but instead a 40 μm thick porous layer is added, are shown with a star in the same figure. Fig. 4 shows the temperature on the heater for a 5 μm thick porous membrane and a cavity of variable thickness underneath. A comparison between isolation by a 40 μm compact porous silicon structure and a structure with 20 μm porous silicon membrane on 20 μm air-gap is shown in fig.5. The heater is located at the middle of the membrane.

It is also the object of the present patent to provide a technique based on the use of the porous silicon/air gap technology for the formation of a pipe under the active elements of the device, which may be used as a flow channel, open on its two endpoints. The main advantage of this technology is that microflows can be formed and measured. This technology also offers important advantages in the case of liquid flows, since the liquid will not be in contact with the active elements of the sensor and so there is no need for

complicated passivation schemes. It also offers advantages in gas flow measurements if the gas is corrosive.

It is also the object of the present patent to provide a thermal sensor device for gas sensing based on the use of porous silicon/air gap technology for local thermal isolation on silicon.

It is also the object of the present patent to provide a silicon thermal sensor for detection of infrared radiation, based on the use of porous silicon/air gap technology for local thermal isolation on silicon.

It is also the object of the present patent to provide a silicon thermal device for thermoelectric power generation, based on the use of porous silicon/air gap technology for local thermal isolation on silicon.

It is also the object of the present patent to provide a silicon thermal device for humidity sensing, based on the use of porous silicon/air gap technology for local thermal isolation on silicon.

Brief description of drawings

Fig. 1 is a schematic representation of the porous silicon layer over a cavity in bulk crystalline silicon.

Fig. 2 shows a schematic view of a thermal sensor using porous silicon/air gap technology.

Fig. 3 shows the temperature increase on heater for thermal isolation by porous silicon of variable thickness over an air-gap.

Fig. 4 shows the temperature increase on heater for thermal isolation by an air-gap of variable depth underneath a porous silicon layer.

Fig. 5 shows the temperature distribution around the heater for thermal isolation by porous silicon and by porous silicon over an air-gap.

Fig.6 is a schematic view of the flow sensor with a microchannel underneath.

Description of the preferred embodiments

Fig.1 is a schematic representation of a silicon substrate (1) with a porous silicon layer (2) on top of a cavity (3). The whole structure is used for local thermal isolation on bulk silicon.

Fig.2 is a schematic representation of a silicon thermal gas flow sensor. The base material is p-type silicon (1) in which a porous silicon membrane (2) with a cavity (3) underneath is formed.

On top of the porous silicon cavity area a polysilicon resistor (4) is formed and two series of thermocouples are integrated on each side of this resistor (5, 6). The hot contacts (7) of these thermopiles lie on porous silicon and the cold contacts (8) on bulk crystalline silicon. There are also aluminum pads (9) used as electrical contacts.

Fig. 3 shows the temperature increase on heater for thermal isolation by porous silicon of variable thickness over an air-gap.

Fig. 4 shows the temperature increase on heater for thermal isolation by an air-gap of variable depth underneath a porous silicon layer.

Fig. 5 shows the temperature distribution around the heater for thermal isolation by 40 μm thick porous silicon film and by 20 μm thick porous silicon membrane over an 20 μm air-gap.

Fig. 6 A microfluidic device based on the use of porous silicon/air-gap technology is shown in this figure. In (a) the top view and in (b) a cross sectional representation is shown. (1) is the silicon substrate, (2) the porous silicon layer, (3) the microfluidic channel between 3(a) and 3(b), (4) is a polycrystalline silicon resistor used as heater, (10) are polycrystalline silicon resistors used as temperature sensing elements, (11) are aluminum current lines, (9) are aluminum contact pads.

Claims

What is claimed is:

1. A thermal flow sensor using porous silicon/air gap technology for thermal isolation. This technology is based on using a single electrochemical process to form locally on silicon a cavity sealed with porous silicon by first applying a current density below the value for electropolishing and then applying a current density above this value. The active parts of the device consist of a heater on top of the porous silicon layer and two thermopiles, one on the left and the other on the right side of the resistor. The thermocouples of the thermopiles are made of p-type poly/Al or p-type/n-type poly. Their hot contacts lie on porous silicon and the cold contacts on bulk crystalline silicon. The heater and the thermopiles are connected to contact pads lying on bulk silicon through interconnecting metal lines.

2. An alternative device to that of claim 1, in which a bilayer of SiO_2/polysilicon or silicon nitride/polysilicon is deposited on top of porous silicon, on which the active elements are integrated. The porous silicon membrane may be removed at the end of the fabrication process for even better thermal isolation. The device on the above mentioned membranes (SiO_2/polysilicon or silicon nitride/polysilicon) is suspended over a cavity in bulk crystalline silicon.

3. A thermal flow device, as in claim 1 in which the process described above for the formation of porous silicon/air gap for thermal used to form a microchannel under the active elements of the device composed of a pipe sealed with porous silicon. The active elements of the device are lying on top of the sealed channel, which comprises two openings at the two ends to be used as inlet and outlet of a fluid. Instead of using thermopiles as sensing elements, one resistor at each side of the heater may be integrated, made of polysilicon or another metal. In another alternative, thermopiles may be used.

4. A process of formation of microfluidic channels in bulk silicon, using a combination of electrochemical dissolution of silicon below and above the critical current density for electropolishing. These microchannels may find different interesting applications in drug delivery.

5. A silicon thermal device using porous silicon/air gap technology with various applications, gas sensing, thermoelectric converter etc.

6. A thermoelectric power converter which uses silicon/air gap technology and it is composed of different parts of porous silicon sealed cavities. The hot contacts of integrated thermopiles lie on porous silicon membrane, while their cold contacts lie on bulk silicon.

7. A humidity silicon thermal sensor using silicon/air-gap technology for local thermal isolation on silicon.

8. An infrared silicon thermal sensor for the detection of IR radiation, based on porous silicon/air-gap technology.

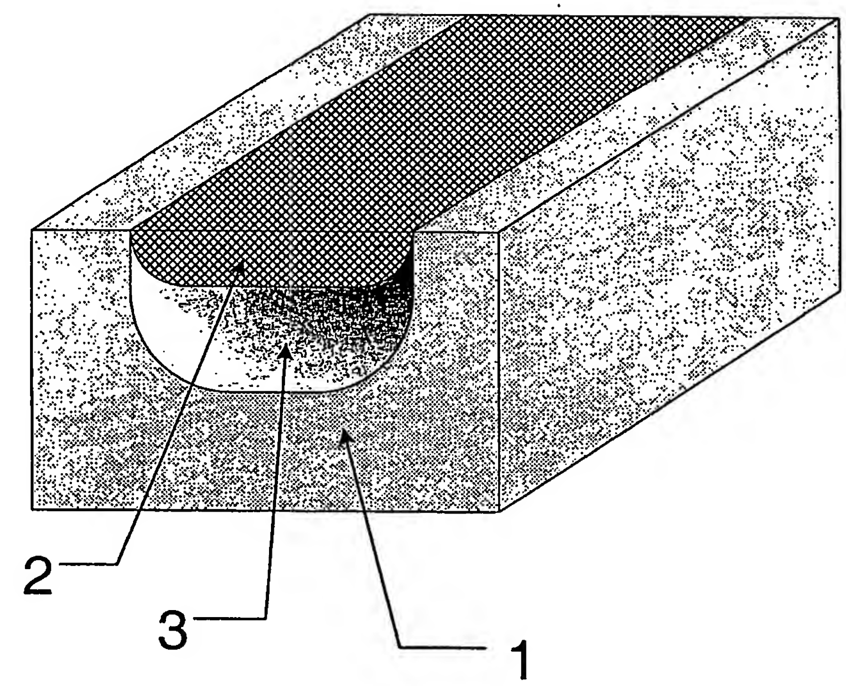


Figure 1

20020100037

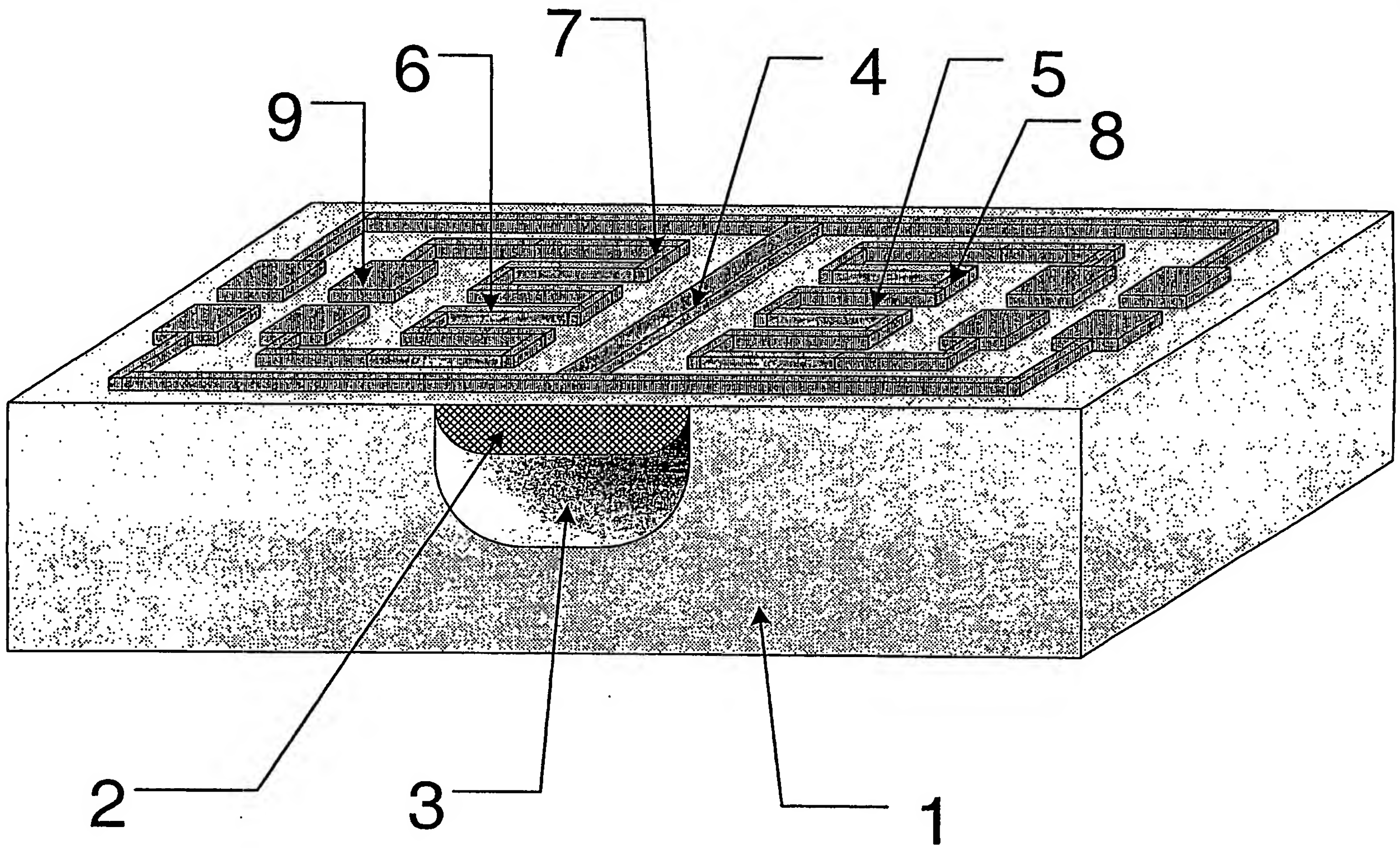
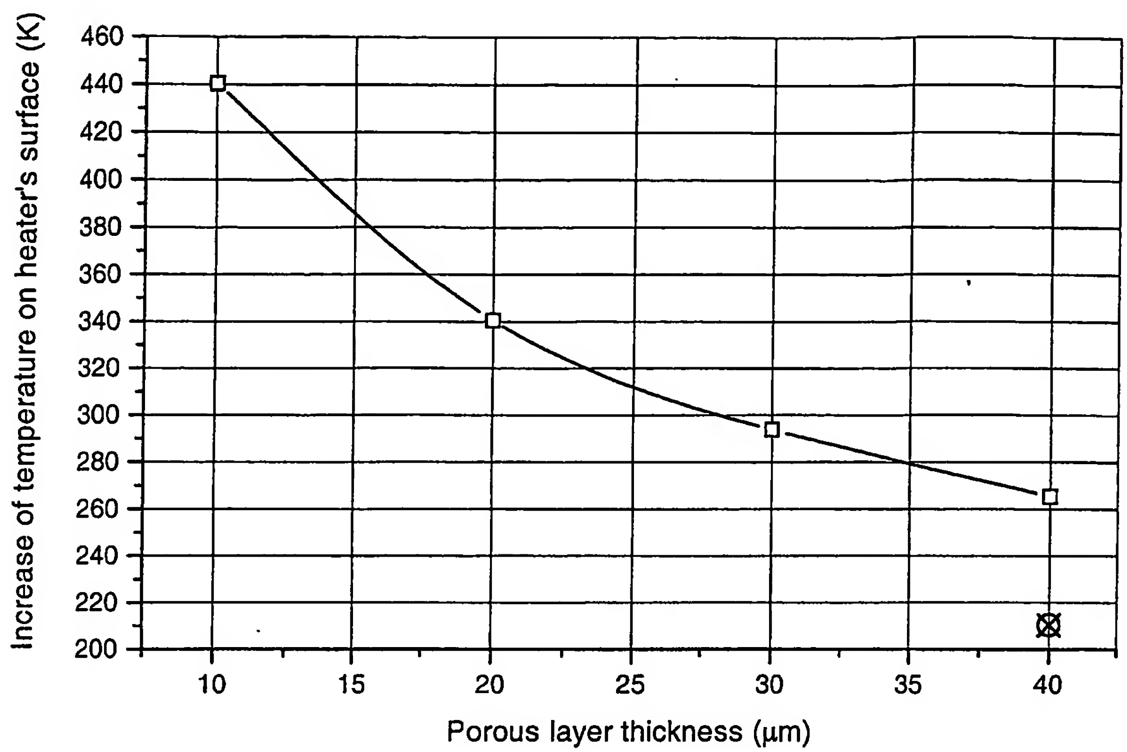


Figure 2



Increase of temperature on heater's surface (K)
460
440
420
400
380
360
340
320
300
280
260
240
220
200
10
15
20
25
30
35
40
Porous layer thickness (μm)

Figure 3

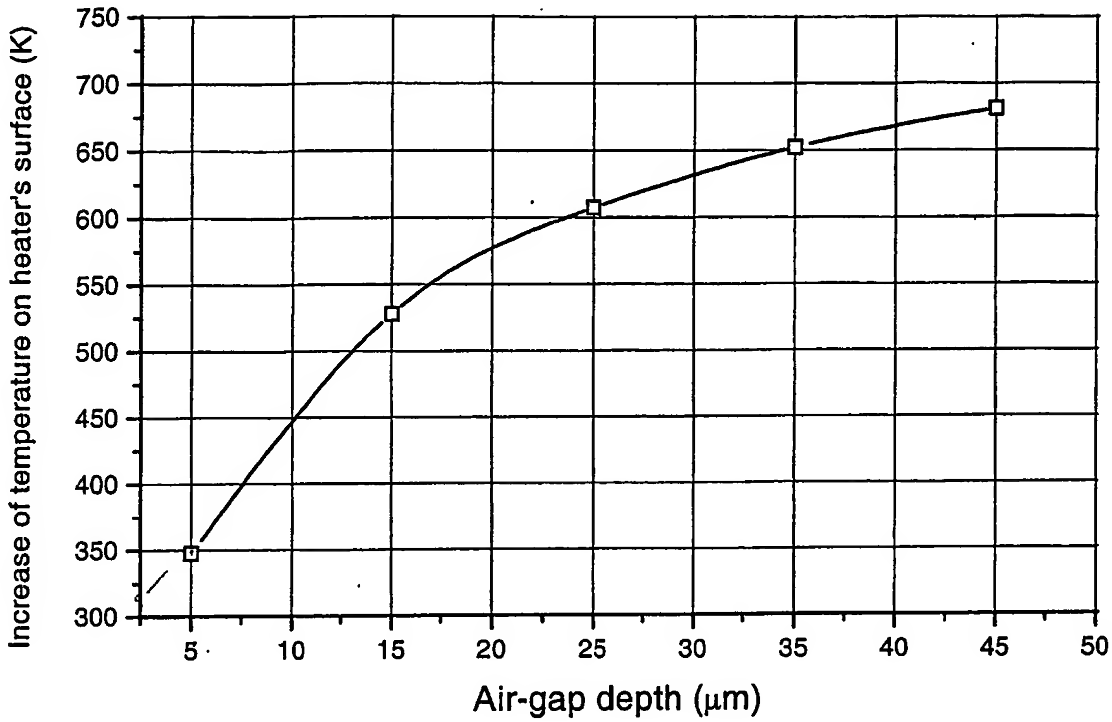

Increase of temperature on heater's surface (K)
750
700
650
600
550
500
450
400
350
300
5
10
15
20
25
30
35
40
45
50
Air-gap depth (μm)

FIGURE 4

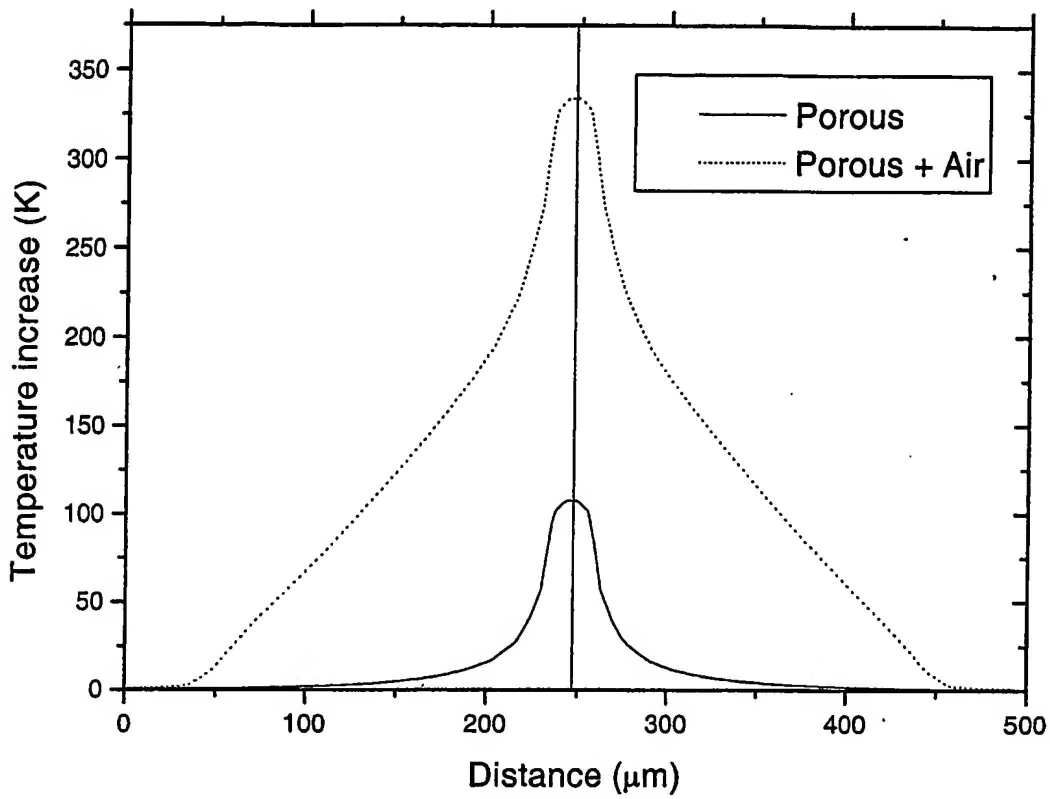

Porous
Porous + Air
Temperature increase (K)
350
300
250
200
150
100
50
0
0
100
200
300
400
500
Distance (μm)

FIGURE 5

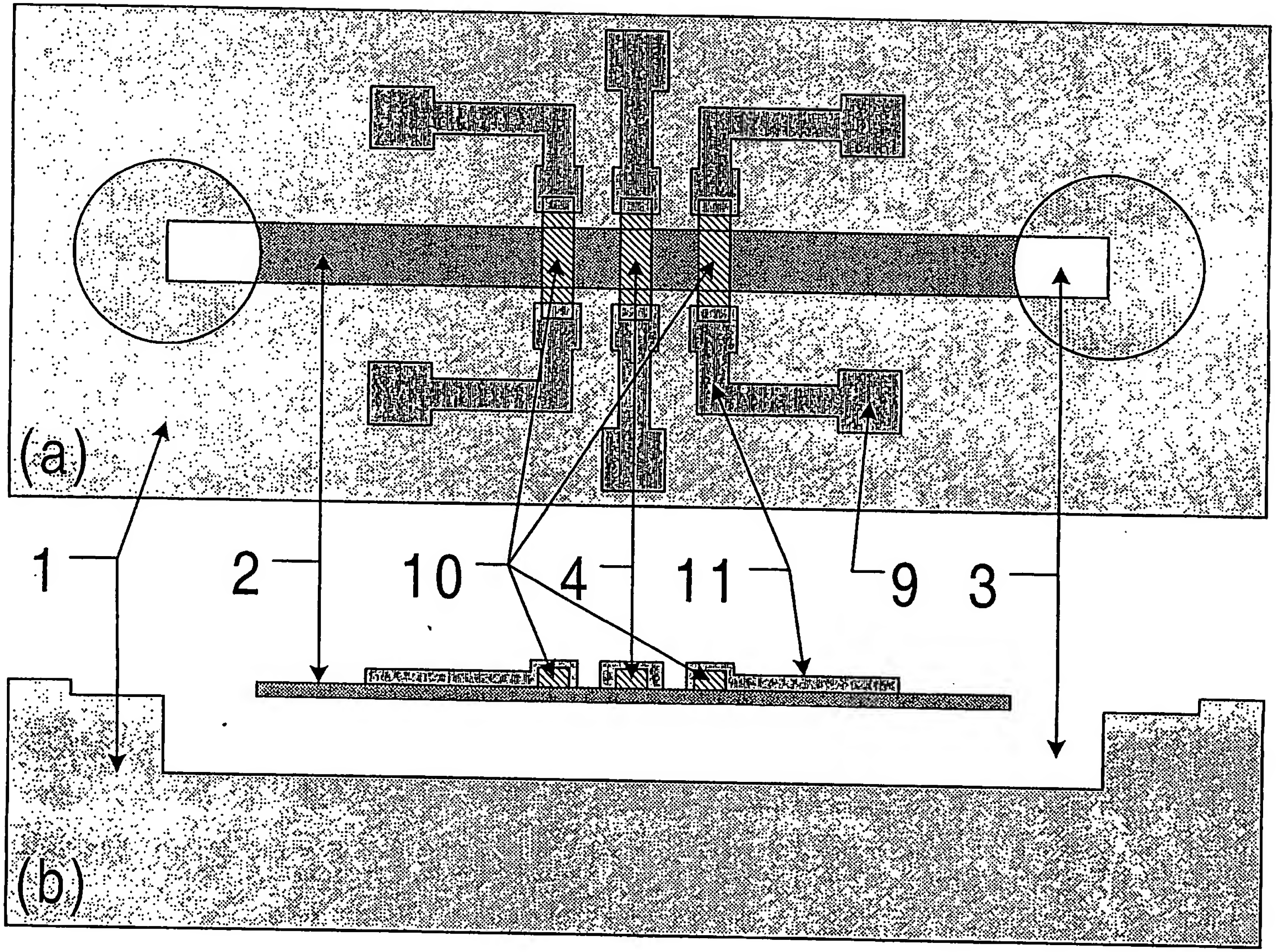


Figure 6

"Low Power Silicon Thermal Flow Sensors and Microfluidic Devices Using Porous Silicon Sealed Air Cavity or Microchannels"

ABSTRACT

This invention provides a miniaturized silicon thermal flow sensor with improved characteristics, based on the use of two series of integrated thermocouples on each side of a heater, all integrated on a porous silicon membrane on top of an air cavity. Porous silicon with the air gap underneath provides very good thermal isolation for the sensor elements, so as the power needed to maintain the heater at a given temperature is very low. The formation process of the porous silicon membrane with the air gap underneath is a two-step single electrochemical process. It is based on the fact that when the anodic current is relatively low, we are in a regime of porous silicon formation, while if this current exceeds a certain value we turn into a regime of electropolishing. The process starts at low current to form porous silicon and it is then turned into electropolishing conditions to form the cavity underneath.

Furthermore the present invention provides a method for the formation of microfluidic channels using the same technique of porous silicon and air gap formation.

Various types of thermal sensor devices, such as flow sensors, gas sensors, IR detectors, humidity sensors and thermoelectric power generators are described using the proposed methodology.